Stock Assessments for British Columbia Herring in 1982 and Forecasts of the Potential Catch in 1983

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ABSTRACT

Stocker, M., V. Haist, and D. Fournier. 1983. Stock assessments for British Columbia herring in 1982 and forecasts of the potential catch in 1983. Can. Tech. Rep. Fish. Aquat. Sci. 1158: ix + 53 p.

Herring stock abundance in British Columbia waters was assessed for 1982, and forecasts were made for 1983 using three methods: (1) Hourston's method, (2) age-structured model analysis, and (3) surplus production model analysis.

The abundance of the 1982 adult herring run in British Columbia waters assessed by Hourston's method was 430,000 t. This is an increase of 93,000 t (28%) from 1981. The 1983 run is forecast at 367,000 t with average recruitment. The 1983 forecasts for poor and good recruitment are 294,000 t and 487,000 t respectively. Average recruitment would provide a potential catch of 201,000 t. This unusually high catch level results primarily from an over estimate of the 1982 spawning stock in the Nanaimo-Comox management unit, due to inaccurate egg survival rates used in estimating spawners.

For the age-structured method and the surplus production method, a catch quota is recommended to regulate the fisheries. The recommended target quota is 20% of the average total forecast population biomass. The quotas for 1983 for the age-structured method and the surplus production method for the entire British Columbia coast are 95,000 t and 76,000 t, respectively.

Under conservative management and other constraints encountered administering fisheries, the catch levels recommended herein may be substantially reduced.

Key words: Clupea harengus pallasi, Pacific herring, stock assessment, forecasts, surplus production, age-structured analysis.

RÉSUMÉ

Stocker, M., V. Haist, and D. Fournier. 1983. Stock assessments for British Columbia herring in 1982 and forecasts of the potential catch in 1983. Can. Tech. Rep. Fish. Aquat. Sci. 1158: ix + 53 p.

Nous avons évalué l'abondance du stock de hareng de la Colombie-Britannique en 1982 et nous avons formulé des prévisions pour 1983 à l'aide des trois méthodes suivantes: (1) la méthode de Hourston, (2) l'analyse du modèle de la structure par âge et (3) l'analyse du modèle de la production excédentaire.

Selon les résultats obtenus à l'aide de la méthode de Hourston, l'abondance des harengs adultes au cours de la remonte de 1982 en Colombie-Britannique s'élève à 430 000 t, soit une augmentation de 93 000 t par rapport à 1981. Nous prévoyons que la remonte de 1983 totalisera 367 000 t en fonction d'un recrutement moyen. Ces prévisions se chiffrent à 294 000 t et 487 000 t en fonction d'un rendement pauvre et bon respectivement. Un rendement moyen engendrerait une prise potentielle de 201 000 t. Ce niveau de prise anormalement élevé provient surtout d'une surestimation du stock reproducteur de 1982 dans l'unité de gestion de Nanaimo-Comox, surestimation causée par des taux inexacts de survie des oeufs utilisés pour l'évaluation du nombre de géniteurs.

Par rapport aux résultats obentus à l'aide de l'analyse du modèle de la structure par âge et de la production excédentaire, nous recommandons un contingentement du prises pour la gestion des la pêche. Le contingent visé représente 20% de la biomasse totale moyenne de la population prévue. Dans le cas de ces deux méthodes, les contingents de 1983, pour toute la côte de la Colombie-Britannique, s'élèvent à 95 000 t et à 76 000 t respectivement.

Les niveaux de prise recommandés ci-dessus seront peut-être considérablement réduits dans le cadre d'une gestion prudente ou à cause de diverses contraintes liées à l'administration des pêches.

Mots-clés: Clupea harengus pallasi, hareng du Pacifique, évaluation de stock, prévisions, production excédentaire, analyse de la structure par âge.

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FOREWORD

This report was prepared by the Population Dynamics Unit of the Herring Section (Fisheries Research Branch), and contains proposed catch levels for herring for the 1982/83 season. These recommended catches are based primarily on biological considerations, and may vary with those finally adopted by the Herring Stock Assessment Committee. The final fishing plans adopted by Fisheries Management will be based not only on biological considerations, but also economic and social, enforcement, and other factors.

Results contained in this report were presented to the Herring Stock Assessment Committee in September of 1982.

ACKNOWLEDGEMENTS

This document is the first report containing alternate assessments of herring stocks off the west coast of Canada together with recommendations on catch limits for the 1982/83 herring season. It not only presents the efforts of the Population Dynamics Program but numerous other members of the Herring Section staff play key roles in collection and processing of data. The ages of herring from the 1982 samples were determined by the Pacific Biological Station Ageing Unit. Also, Field Services personnel and contractors contribute to this effort.

1. INTRODUCTION

1.1 General

Forecasting the potential catch that can be removed from herring stocks requires assessing the status and determining which factors affect stock dynamics. Traditionally, yield models have assumed equilibrium conditions implying no changes in age structure, growth, or mortality over time. However, herring are strongly affected by changes in conditions thus making equilibrium models unattractive. The methods we use try to estimate current stock conditions on the basis of which potential catches are recommended that will not have deleterious effects on the stocks.

In this report we present three methods to assess herring stock conditions: (1) Hourston's method (Hourston and Schweigert 1981), (2) age-structured model analysis (Fournier and Archibald 1982), and (3) surplus production model analysis. The first two methods use age composition data, and all three methods use spawn deposition information.

1.2 Data Base

The main data inputs for these stock assessment methods are spawn survey data, commercial catch landing data, and age composition data from biological samples of both commercial catches and research cruises. These data are available on computer files in a consistent format for the period 1951 to 1982. This time span includes the reduction fishery period to 1968 and the subsequent "roe" fishery period starting in the early 1970s.

Of the three sets of information the spawn data has the largest measurement errors. We feel that the quality of spawn surveys has improved greatly over the 32 year span of these observations. This improvement is a result of increased numbers of people and vessels being involved in spawn surveys, increased attention to data measurements, increased coverage of subtidal spawnings, and increased research on estimating egg deposition from spawn observations. Hourston's method has attempted to utilize the increased accuracy of the spawn data by incorporating more sophisticated formulas for estimating egg deposition from survey information as more detailed data were collected. The only consistent observations made during the entire 32 years of spawn surveys are the length, the width, and a measure of intensity of spawnings. The surplus production and age-structured models use a spawn index calculated by summing the length times the intensity of all spawnings in an area. Observations on width are not used in these two models because they probably have greater measurement errors as people were unaware of subtidal spawnings in the earlier years. The two models evaluate the implications of time dependent trends in the spawn index.

Catch information was obtained from landing slip data. Hourston's method uses only roe fishery catch data for the period 1972-82. The other two methods use all landing slip data for the season (seasons run from July 1 to June 30). The 1982 catch figures are based on hailed estimates because sales slip data were not available for timely analysis. The sales slips record

catch in tons. Numbers of fish in the catch, for use in the age-structured model, were calculated using the average fish weight from catch samples for the season. A small amount of catch obtained off the west coast of Vancouver Island during the reduction period is not included in the W.C.V.I. data set, but is included in the data for the entire south coast. These fish, caught offshore in the summer, could be either west coast or Strait of Georgia spawners.

Age structure data is used in both Hourston's method and in the age-structured model. For the age-structured model all catch samples from a geographical area are used in the estimate of proportion at age for the period of reduction fisheries. However, the various fisheries since the early 1970s have different age selectivities so the age structure samples have been weighted by the relative amounts of catch for each type of fishery (gillnet roe, seine roe, other). Hourston's method uses age structure information which is compiled by section (see Hourston and Hamer 1979 for section definitions) and week for each fishery. The age structure of the spawning populations is estimated from seine sampling data.

Additional information obtained from the biological sampling data base is used in Hourston's method and in the age-structured model. This includes data on age specific fecundities, fish weights, and percent females.

1.3 Stock considerations

For Hourston's method (Section 2) stock assessments are conducted separately for each management unit (Hourston and Hamer 1979). These geographic regions (Fig. 1.1) support or have the potential for roe fisheries and include the spawning ground utilized by the fish (Hourston 1982).

For the age-structured model analysis (Section 3), and the surplus production model analysis (Section 4) stock assessments are conducted separately for each of seven data sets. Two of these group the entire north and the entire south into two separate "stocks". The other five data sets (Fig. 1.2) look at three "stocks" in the north (Queen Charlotte Islands, north coast, central coast), and two "stocks" in the south (west coast of Vancouver Island, Strait of Georgia and Johnstone Strait). These stock groupings are a re-definition of the management unit stock concept. The assumption that spawners return to the same management unit in which they previously spawned has been relaxed in this re-definition. The five geographic regions are more in line with west coast herring populations that were originally identified on the basis of mean vertebral number (Tester 1937, 1949), and the division level of data aggregation (Hourston and Hamer 1979).

1.4 Harvesting strategies

For Hourston's method the average potential catch for each management unit is forecast by subtracting the desired escapement from the forecasted run (Hourston and Schweigert 1981). Forecasts of runs are made by estimating returning adults and new recruits. Desired escapements, for this method, have been set at levels that have historically provided better than average recruitment. A range of anticipated catches is forecast for good and

poor recruitment. This procedure resembles a so-called "fixed escapement" policy that should maintain populations at their point of maximum production.

For the age-structured method, and the surplus production method a catch quota is recommended to regulate the fisheries. The recommended target quota should be 20% of the average total forecast population biomass. These low exploitation rates will provide less variable yields, than fixed escapement policies, and permit informative variation in spawning stocks. They may also dampen wide fluctuations due to dome shaped recruitment relationships (ESSA 1982). High and low potential catches are predicted from observed variation around the production relationships for the surplus production method.

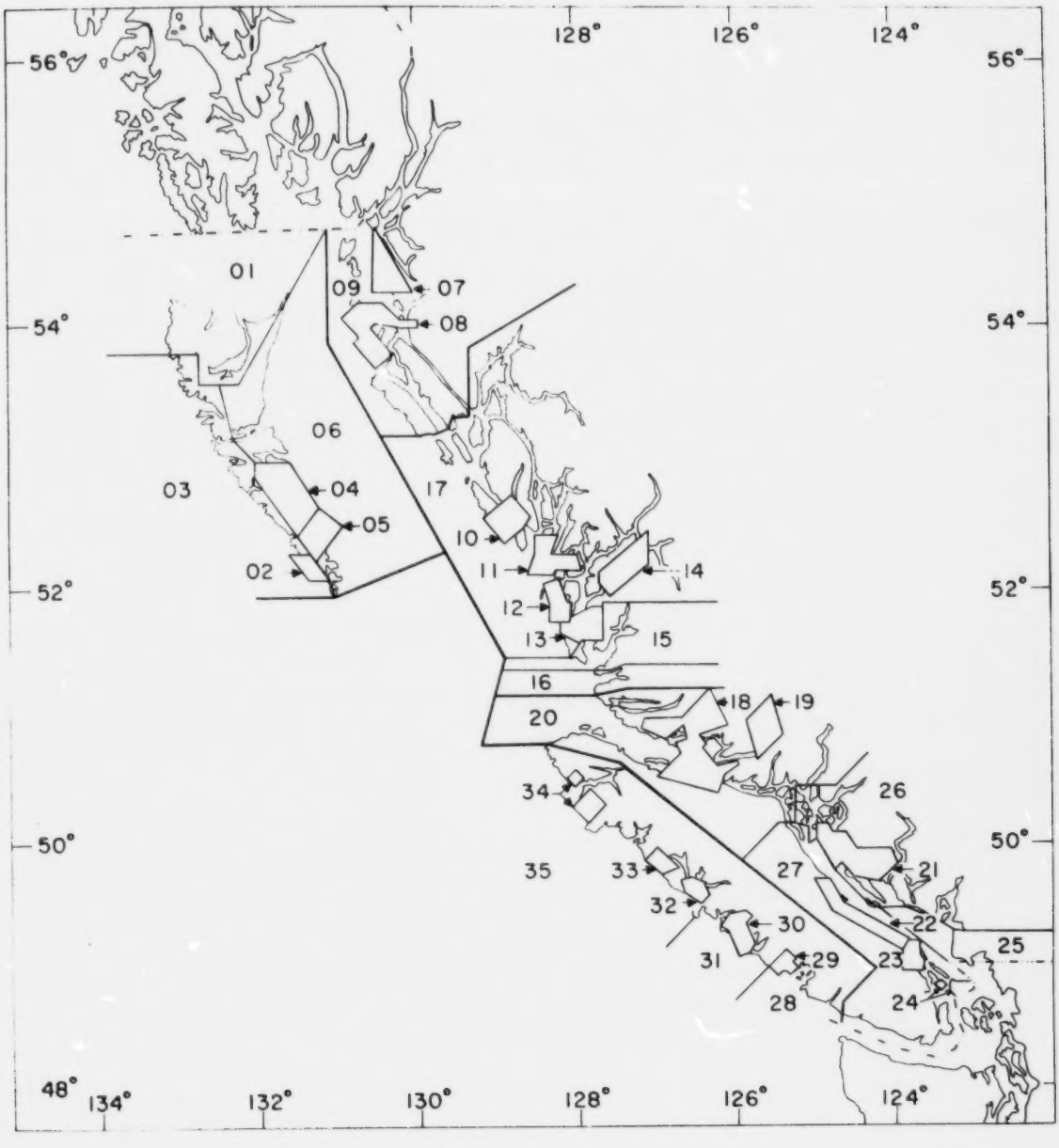

Fig. 1.1. Management units for British Columbia herring roe fisheries.

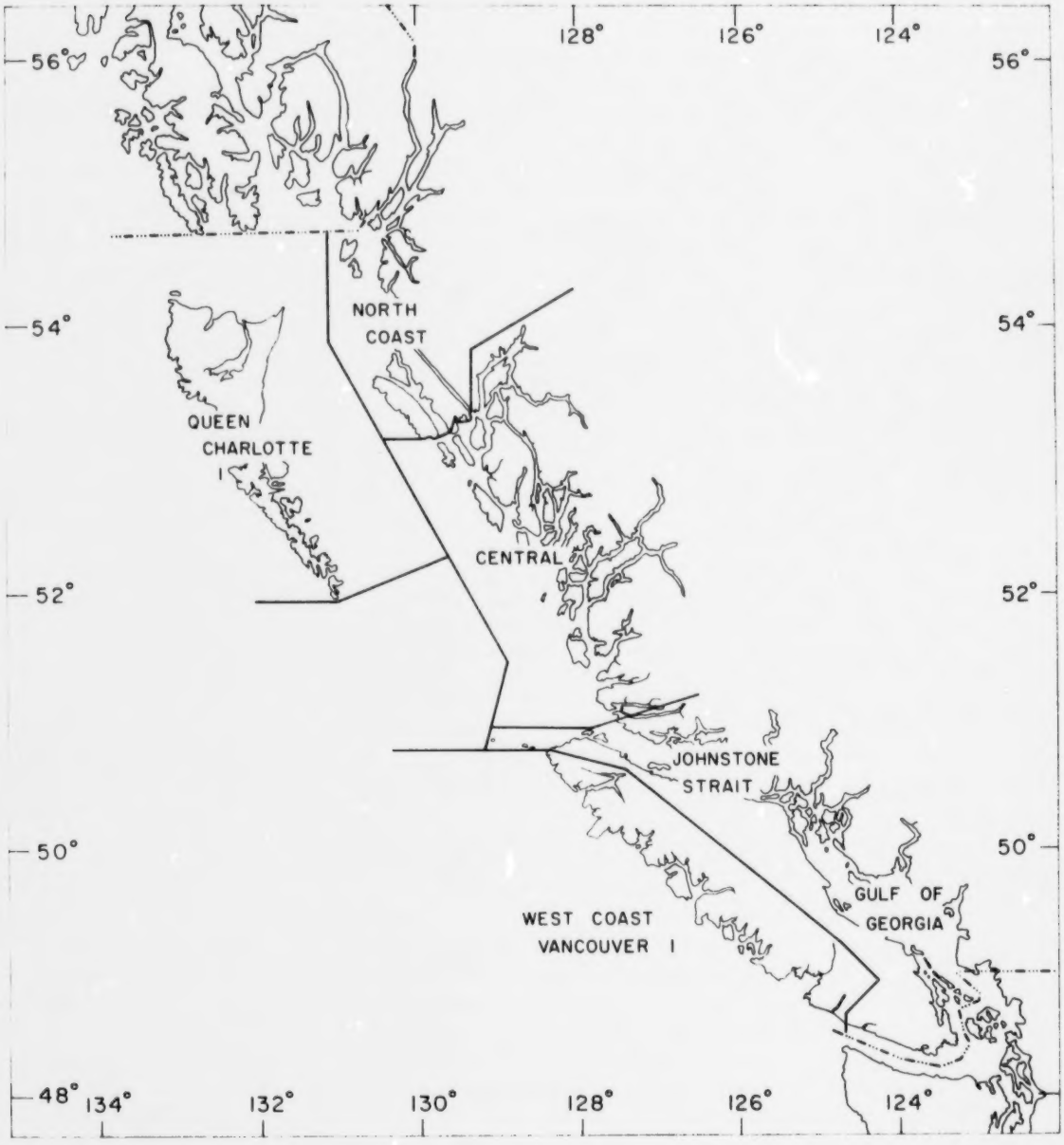

Fig. 1.2. Herring stock groupings for age-structured model analysis, and surplus production model analysis.

2. HOURSTON'S METHOD

2.1 Introduction

Hourston's method for assessing and forecasting stock abundance was developed explicitly for the B.C. herring roe fisheries. The roe fisheries, which developed through the early 1970s, occur on geographically segregated areas at virtually the same time resulting in the need for quantitative forecasts for each potential fishery. To assess and forecast stock abundance a computer analysis was developed which incorporates catch, spawn deposition, and sampling data (Hourston and Schweigert 1981).

The analysis is set up in two parts - the assessment of spawning stocks in a given year, and the forecast of runs in the following year. Spawning stock abundance is primarily dependent on the estimates of egg deposition calculated from fishery officer spawn surveys. Forecasts to management units have two components. First, the estimate of adults (repeat spawners) obtained from applying survival rates at age (Tester 1955) to the previous year's spawning stock. Second, the estimate of recruitment which is an average estimated for the stock in previous years.

The forecasting analysis involves two basic assumptions. Firstly, that adults return to the same management unit, or that immigration balances emigration in a management unit. Secondly, that all 3 yr old and younger fish are new recruits, and all 4 yr old and older fish are repeat spawners. Neither of these assumptions is likely to be met for all management units (Hourston 1981).

2.2 Methods

Only a brief description of this stock assessment method is given here as detailed accounts have been published elsewhere (Hourston and Schweigert 1981).

The spawn data collected by fisheries officers in recent years includes area of spawn, layers of eggs, and percent contribution of various substrates. These are converted to estimates of egg deposition using tables of eggs per unit area for the substrates (Haegele et al. 1979) and dividing by egg survival factors for the area. The egg survival factors are included to account for loss of eggs between spawnings and surveys (predation, storms, etc.), and incomplete coverage of areas. Survival factors have been updated using adjustments determined from comparing fisheries officer surveys to diver surveys for all areas of dual coverage (Table 2.1).

The number of spawners at age in an area is calculated using age composition, percent females, and fecundity information from sample data along with the estimates of numbers of eggs deposited. The forecast of returning adults in the coming year is then determined by applying age-specific survival rates according to Tester (1955) as follows:

Age	3	4	5	6	7	8	9
survival rate	0.6839	0.6005	0.5273	0.4630	0.4066	0.3570	0.3135

Recruits to the spawning stock are assumed to be all 3 yr old fish and younger. Using recruitment estimates for the period 1972-1982 three levels of recruitment are calculated using the average for the lowest 25%, all, and the highest 25% of the years.

2.3 Status of stocks

2.3.1 North

Estimates of spawners and hailed roe catches in 1982 and of total pre-fishery abundance for the period 1973-82 for the northern management units and divisions are shown in Table 2.2. The 1982 pre-fishery biomass for the Queen Charlotte Islands was estimated at 46,500 tons. This represents a 39% increase over the 1981 pre-fishery biomass. Most management units in this division show an increase in stock abundance over the previous year with the largest increases occurring on the west coast of the Queen Charlottes. For the north coast division the estimated pre-fishery biomass was 21,500 t which is an increase of 28% over the previous year. This is however considerably lower than estimated abundances in the mid 1970s. The central coast pre-fishery biomass for 1982 was estimated as 60,300 tons. This represents an increase of 24% over the previous year and is the highest abundance estimate for the 10 year period.

Generally, the northern stocks with the exception of the north coast appear to be in good shape with 1982 pre-fishery abundances as high as the maximum observed in the previous 10 years. However, shifts in abundance within the division level are indicated by the data. These are a northerly shift within the central coast and a shift to the west coast of the Queen Charlotte Islands.

2.3.2 South

Estimates of spawners and hailed roe catches in 1982 and of total pre-fishery abundance for the period 1973-82 for the southern management units and divisions are shown in Table 2.2. The estimated pre-fishery biomass in the Johnstone Strait division in 1982 was 6,900 tons. This is a substantial decrease of 60% from the 1981 estimate. In the Strait of Georgia division the 1982 pre-fishery biomass estimate of 252,700 t represents an increase of 80% over the previous year. This is by far the highest abundance estimated for the 10 year period and results primarily from the 180,000 t estimate in the Nanaimo-Comox management unit. The stock assessment for the Nanaimo-Comox management unit is not considered very accurate by the biologists and fisheries officers who were in the field prior to and during the 1982 roe fishery. They feel this estimate is about twice as high as it should be.

This can result from inaccurate egg survival factors which are used in estimating the number of spawners. The factors used for this management unit (include sections 142, 143, 144, 172) were all determined in conjunction with diver surveys in 1981, however they may not reflect yearly variation in egg densities on sparse vegetation.

The 1982 pre-fishery biomass estimate for the west coast of Vancouver Island was 42,400 tons. This is a decrease of 67% from the previous year and is the lowest estimate for the 1973-82 period. The estimated abundances in 1982 for all management units of the west coast of Vancouver Island are substantially lower than their 10 year averages.

2.4 Forecasts

Forecasts of 1983 runs to management units and to divisions assuming poor, average, and good recruitment are shown in Table 2.3. Spawning requirements were determined in a qualitative way based on historical records of area and substrate utilized, and optimal egg deposition for hatching viable larvae (Hourston 1981). The potential catch is the difference between spawning requirements and the three levels of forecast runs.

These forecasts assume that all spawning stocks are potentially fishable. This, however, is not true because of: (1) spawn timing considerations, (2) areas containing primarily resident stocks, and (3) areas which can not be assessed in-season. A more realistic assumption for managers would be that some fraction of the potential catch (say 50-60%) is potentially fishable.

Given average recruitment the potential catch in 1983 is 18,900 t for the Queen Charlotte Islands, 6,500 t for the north coast, and 24,900 t for the central coast. Combined, this would be a potential catch of 50,300 t for the northern district. Assuming poor recruitment, the potential catch for the entire northern district would be 36,600 t.

The potential catch, assuming average recruitment is 141,300 t for the Strait of Georgia and 5,800 t for the west coast of Vancouver Island. Because of potential error in the 1982 spawn assessment for the Strait of Georgia the potential catch for this area is probably unrealistically high. The forecast runs for the west coast of Vancouver Island given poor recruitment indicate no surplus stocks to support a fishery in 1983. Even under the assumption of average recruitment only 3 of the 7 management units in this division would have runs in excess of spawning requirements.

Table 2.1 Egg survival factors by section used in assessing 1982 spawn deposition.

Section[a]	Survival Factor	Section	Survival Factor
002	0.333	102	0.333
003	0.333	103	0.333
004	0.333	123	0.333
005	0.333	126	0.333
006	0.333	127	0.333
012	0.333	131	0.333
021	0.333	132	0.333
022	0.333	134	0.333
023	0.333*	137	0.333
024	1.000*	142	0.333*
025	0.666	143	0.333*
032	0.333	144	0.666*
033	0.666*	152	0.666*
042	0.666*	165	0.333
051	0.333	172	0.666*
052	1.000	173	0.333*
061	0.333	182	0.666
067	0.333	183	0.333
071	0.333	232	0.333*
072	1.000*	233	0.333*
074	0.333*	243	0.333*
075	0.333*	244	0.333
076	0.333	245	0.500*
083	0.333	253	0.333
085	0.333*	254	0.333
093	0.333	272	1.000
		273	1.000

[a]For section coding see Hourston and Hamer (1979).

*Indicates areas where values were determined in conjunction with diver surveys.

Table 2.2 Catch (tons), spawners (tons) for 1982, and total abundance (tons) for 1973 to 1982 by management unit for Queen Charlotte Island division.

Year	Total QCI Division	Management Unit: North Coast 01	Louscoone 02	Other Area 2W 03	Laskeek Bay 04	Skincuttle 05	Other Area 2E 06
			Gillnet Catch				
1982	1297	-	-	-	-	1297	-
			Seine Catch				
1982	4586	-	-	1451	2155	675	305
			Spawners				
1982	40643	4833	5189	13110	1573	12209	3729
			Total Abundance				
1982	46524	4833	5189	14561	3727	14181	4033
1981	33364	1569	1472	6333	5205	15480	3305
1980	23806	3997	2298	3044	1794	12673	-
1979	27346	1855	1358	2705	663	14526	6239
1978	40183	6283	3129	1859	18	22096	6798
1977	34745	3499	3752	2661	-	16740	8093
1976	41855	4961	9710	760	812	16744	8868
1975	31825	2045	9360	2236	-	10089	8095
1974	29903	4947	5090	3684	-	7645	8537
1973	25192	-	3644	3309	-	5578	12661

Table 2.2 (cont'd) Catch (tons), spawners (tons) for 1982, and total abundance (tons) for 1973 to 1982 by management unit for north coast division.

Year	Total North Coast	Management Unit: Chatham Sound 07	Management Unit: Porcher Island 08	Management Unit: Other North Coast 09
			Gillnet Catch	
1982	-	-	-	-
			Seine Catch	
1982	187	-	187	-
			Spawners	
1982	21294	17176	3595	523
			Total Abundance	
1982	21481	17176	3782	523
1981	17564	8554	7498	1512
1980	18255	5262	12552	441
1979	43154	32322	10832	-
1978	13296	5468	7690	138
1977	38367	17335	20923	109
1976	60750	42923	17827	-
1975	39215	21114	17980	121
1974	23115	7931	14910	274
1973	31729	16530	15199	-

Table 2.2 (cont'd) Catch (tons), spawners (tons) for 1982, and total abundance (tons) for 1973 to 1982 by management unit for central division.

Year	Total Central Division	Management Unit							
		Kitasu Bay 10	Milbanke Sound 11	Queens Sound 12	Kwakshua Channel 13	Burke Channel 14	Rivers Inlet 15	Smith Inlet 16	Other Central 17
				Gillnet Catch					
1982	4175	407	3768	-	-	-	-	-	-
				Seine Catch					
1982	3025	-	3025	-	-	-	-	-	-
				Spawners					
1982	53101	12106	27033	1726	5428	-	1941	4184	683
				Total Abundance					
1982	60301	12513	33827	1726	5428	-	1941	4184	683
1981	48421	13428	22228	3388	7484	637	95	535	626
1980	43610	8701	20961	5839	2593	-	382	1788	3346
1979	19292	2152	6490	3817	2137	2904	447	416	929
1978	32326	5629	15028	6949	2246	-	1456	780	238
1977	42795	3413	18671	11115	2683	3634	2724	168	387
1976	41132	4477	16752	7028	4084	4571	1755	458	2007
1975	38740	8278	9493	5500	5836	2066	5558	687	1322
1974	27350	3915	9275	5678	2515	2021	2789	609	548
1973	52569	12794	15598	4631	3517	3906	9877	956	1290

Table 2.2 (cont'd) Catch (tons), spawners (tons) for 1982, and total abundance (tons) for 1973 to 1982 by management unit for Johnstone Strait division.

Year	Total Johnstone Division	Management Unit: Upper Johnstone 18	Knight Inlet 19	Other Johnstone 20
		Gillnet Catch		
1982	-	-	-	-
		Seine Catch		
1982	-	-	-	-
		Spawners		
1982	6914	790	5368	756
		Total Abundance		
1982	6914	790	5368	756
1981	17185	4481	1256	11448
1980	17764	8403	1779	7582
1979	4583	227	200	4156
1978	4202	2201	1193	808
1977	16551	6271	7289	2991
1976	21847	10741	9539	1567
1975	45422	19402	21315	4705
1974	30334	8359	17238	4737
1973	25333	6967	16401	1965

Table 2.2 (cont'd) Catch (tons), spawners (tons) for 1982, and total abundance (tons) by management unit for Strait of Georgia division.

Year	Total Strait of Georgia Division	Management Unit						
		Powell River 21	Nanaimo Comox 22	Yellow Point 23	Ganges Plumper 24	Area 29 25	Other Mainland 26	Gulf Island 27
				Gillnet Catch				
1982	6600	-	6600	-	-	-	-	-
				Seine Catch				
1982	3876	-	-	1697	-	-	-	2179
				Spawners				
1982	242176	17321	172965	36015	638	-	397	14840
				Total Abundance				
1982	252652	17321	179565	37712	638	-	397	17019
1981	139954	14359	101358	21517	2247	-	13	460
1980	81887	5840	63599	8635	852	663	1368	930
1979	141557	48962	80420	10547	742	-	-	886
1978	128212	22448	90750	10740	1771	120	3	2380
1977	118996	36769	66490	11971	1425	1068	370	883
1976	133479	22130	89250	15053	1976	3139	589	1342
1975	108147	15428	51734	7327	24419	6067	573	2599
1974	154609	8439	80582	39353	23066	2564	497	109
1973	53910	17357	24183	4411	6739	615	346	259

Table 2.2 (cont'd) Catch (tons), spawners (tons) for 1982, and total abundance (tons) for 1973 to 1982 by management unit for West Coast of Vancouver Island division.

Year	Total WCVI Division	Management Unit							
		West Barkley 28	Other Area 23 29	South Clayquot 30	Other Area 24 31	Nootka Sound 32	Nuchatlitz Inlet 33	Quatsino Sound 34	Other Upper West Coast 35
					Gillnet Catch				
1982	3385	-	-	344	541	-	2100	385	15
					Seine Catch				
1982	5208	3983	-	-	810	-	-	415	-
					Spawners				
1982	33796	7777	-	3341	92	7071	9979	5536	-
					Total Abundance				
1982	42389	11760	-	3685	1443	7071	12079	6336	15
1981	71124	15411	3	28405	1971	5503	11675	8156	-
1980	97124	10033	-	33375	3354	-	15027	35335	-
1979	125181	17283	236	23363	3475	46836	15865	18123	-
1978	102611	14434	1666	42145	5356	717	24134	13925	234
1977	117607	38740	2141	48719	4719	919	20937	1028	404
1976	140461	32087	16173	59858	17733	2564	10560	519	967
1975	141197	20056	1272	50999	19054	15389	25832	7084	1511
1974	102434	27673	-	44043	2306	23134	3173	580	1525
1973	62625	17433	185	2769	10452	15226	8574	2330	5656

Table 2.3 Forecast of the 1983 runs and potential catch in tons of fish by management unit for good, average, and poor recruitment.

Division and Management Unit	Adults	Recruits			Run			Spawners	Potential Catch		
		Poor	Average	Good	Poor	Average	Good	Required	Poor	Average	Good
Queen Charlotte Is.											
North Coast	3256.	196.	1212.	2838.	3452.	4468.	6094.	2000.	1452.	2468.	4094.
Louscoone Inlet	3560.	110.	635.	1412.	3670.	4195.	4972.	3000.	670.	1195.	1972.
Other Area 2W	8586.	165.	1005.	2578.	8751.	9591.	11164.	2000.	6751.	7591.	9164.
Laskeek Bay	1113.	4.	262.	837.	1117.	1375.	1950.	4000.	0.	0.	0.
Skincuttle Inlet	9027.	364.	2356.	5398.	9391.	11383.	14425.	7000.	2391.	4383.	7425.
Other Area 2E	3362.	695.	1420.	2384.	4057.	4783.	5746.	1500.	2557.	3283.	4246.
All	28905.	1534.	6889.	15446.	30439.	35795.	44351.	19500.	13821.	18920.	26901.
North Coast											
Chatham Sound	14233.	144.	2314.	5545.	14377.	16546.	19778.	10000.	4377.	6546.	9778.
Porcher Island	2643.	300.	2428.	7644.	2943.	5072.	10287.	10000.	0.	0.	287.
Other North Coast	408.	2.	90.	295.	410.	498.	703.	1000.	0.	0.	0.
All	17284.	446.	4832.	13484.	17730.	22116.	30768.	21000.	4377.	6546.	10065.
Central											
Kitasu Bay	9094.	104.	1460.	3950.	9198.	10555.	13044.	4000.	5198.	6555.	9044.
Milbanke Sound	17080.	790.	2719.	6401.	17871.	19799.	23481.	8000.	9871.	11799.	15481.
Queens Sound	1173.	336.	1139.	2388.	1508.	2311.	3560.	3000.	0.	0.	560.
Kwakshua Channel	3702.	81.	1160.	2639.	3783.	4861.	6341.	2000.	1783.	2861.	4341.
Rivers Inlet	1247.	20.	595.	1682.	1267.	1842.	2928.	1500.	0.	342.	1428.
Smith Inlet	2973.	10.	369.	1052.	2984.	3342.	4026.	500.	2484.	2842.	3526.
Other Central	439.	44.	474.	1478.	483.	914.	1917.	400.	83.	514.	1517.
All	35708.	1386.	7916.	19590.	37094.	43625.	55298.	19400.	19419.	24913.	35898.

Table 2.3 (cont'd) Forecast of the 1983 runs and potential catch in tons of fish by management unit for good, average, and poor recruitment.

Division and Management Unit	Adults	Recruits			Run			Spawners	Potential Catch		
		Poor	Average	Good	Poor	Average	Good	Required	Poor	Average	Good
Johnstone Strait											
Upper Johnstone Str.	617.	64.	1706.	4430.	681.	2323.	5047.	4000.	0.	0.	1047.
Knight Inlet	4856.	162.	893.	2191.	5018.	5749.	7047.	2000.	3018.	3749.	5047.
Other Johnstone Str.	546.	265.	1705.	4159.	811.	2251.	4705.	4000.	0.	0.	705.
All	6019.	491.	4303.	10780.	6510.	10322.	16799.	10000.	3018.	3749.	6799.
Strait of Georgia											
Powell River	11770.	2348.	5209.	9417.	14118.	16979.	21187.	10000.	4118.	6979.	11187.
Nanaimo-Comox	113412.	7333.	26158.	49073.	120744.	139570.	162485.	40000.	80744.	99570.	122485.
Yellow Point	25733.	1244.	7477.	18738.	26977.	33210.	44471.	10000.	16977.	23210.	34471.
Ganges-Plumper	418.	204.	3727.	12187.	622.	4145.	12604.	4000.	0.	145.	8604.
Other Gulf Mainland	276.	6.	182.	473.	282.	458.	748.	300.	0.	158.	448.
Other Gulf Van. Is.	11093.	76.	994.	2735.	11170.	12087.	13829.	800.	10370.	11287.	13029.
All	162702.	11211.	43747.	92623.	173913.	206449.	255323.	65100.	112209.	141349.	190223.
West Coast of Van. Is.											
West Barkely	5141.	1215.	4671.	9308.	6356.	9812.	14449.	10000.	0.	0.	4449.
South Clayoquot	2193.	972.	6746.	15323.	3166.	8940.	17517.	15000.	0.	0.	2517.
Other Area 24	65.	266.	1262.	3064.	331.	1327.	3129.	2000.	0.	0.	1129.
Nootka Sound	5251.	312.	2515.	6546.	5563.	7766.	11797.	6000.	0.	1766.	5797.
Nuchatlitz Inlet	7442.	1314.	4358.	10821.	8756.	11801.	18263.	10000.	0.	1801.	8263.
Quatsino Sound	3835.	86.	4377.	14223.	3921.	8212.	18058.	6000.	0.	2212.	12058.
Other Up. West Coast	0.	9.	436.	1130.	9.	436.	1130.	3000.	0.	0.	0.
All	23928.	4173.	24365.	60416.	28102.	48294.	84344.	52000.	0.	5779.	34214.
All Divisions	274547.	19241.	92053.	212337.	293788.	366600.	486884.	187000.	152844.	201256.	304101.

3. AGE-STRUCTURED MODEL

3.1 Introduction

The use of models utilizing age structure data for stock reconstruction is well documented in fisheries literature. Simple models use only age structure data (eg. cohort analysis); more complex methods incoporate additional information about the stocks (eg. cpue data). The age-structured model used in this analysis is a modification of the model described in Fournier and Archibald (1982). The basic model includes realistic assumptions about the form of both measurement and process errors. A maximum likelihood method is used to simultaneously estimate all model parameters (eg. natural and fishing mortality rates, stock-recruitment parameters). The flexibility of this model to incorporate additional information about the populations has been used to include the spawn survey data available for B.C. herring.

Three structural assumptions are made to include the spawn data in the age-structured model. One is the form of the relationship between the true spawn and the observed spawn, the second is the form of the relationship between escapement and true spawn, and the third is the existence of a spawn-recruitment relationship. Two additional structural assumptions inherent in this model are the form of the catch equations and the form of equations describing natural and fishing mortalities.

Statistical assumptions which are included in the estimation procedure include the form of error in the catch estimates and in the estimates of the age structure. Assumptions are also made regarding the form of errors in the spawn relationships.

3.2 Methods

The general age-structured model used in this analysis has been described in detail elsewhere (Fournier and Archibald 1982); the inclusion of spawn data in the model is also documented (Haist et al. MS in prep). Only a cursory description of the model is included here.

Parameters which are estimated by the model include the instantaneous rates of fishing (F) and natural (M) mortalities as well as the numbers of fish in year i at age j (N_{ij}) for each year of the data series. The estimates are determined by minimizing an objective function which has terms for all components of the model. Simplified versions (variance estimates and constants are not included) of the major components of the objective function are:

- the log likelihood function for the parameters P_{ij} and C_i

$$\sum_{ij} S_{ij} \log P_{ij} - w \sum_{i} (\log O_i - \log C_i)^2$$

- the contribution from the true spawn - escapement relationship

$$- w\sum_{i} \left(\log \left(\sum_{j} f_j N_{ij}\right) - QSP - \log (TS_i)\right)^2$$

- the contribution from the true spawn - recruitment relationship (a Ricker type parameterization is used)

$$- w\sum_{i} \left(\log (N_{i+1,1}) - \log\alpha - \log (TS_i) + \beta TS_i\right)^2$$

- the contribution from the true spawn - observed spawn relationship

$$- w\sum_{i} \left(\log(TS_i) - CSP - \log(OS_i)\right)^2$$

where S_{ij} = the number of fish observed to be of age j in year i

P_{ij} = the actual percentage of fish of age j in the catch in year i

O_i = estimated number of fish caught in year i

C_i = actual number of fish caught in year i

f_j = relative fecundity of fish of age j

TS_i = true spawn in year i

QSP = true spawn - escapement coefficient

OS_i = observed spawn in year i

CSP = true spawn - observed spawn coefficient

α, β = Ricker stock - recruitment parameters

w = penalty weights

The penalty weights (w) are assigned by the user and reflect his intuition about the relative accuracy of the data. The spawn related penalty weights used in all runs in this analysis are :

20 for the true spawn - escapement relationship

10 for the true spawn - observed spawn relationship

5 for the true spawn - recruitment relationship

These penalty weights reflect our belief that herring do not follow a very strong stock - recruitment relationship , and our mistrust of the earlier spawn index data. By placing the highest weight on the true spawn-escapement relationship the true spawn estimates will follow the escapement estimates from the age structure data to a relatively greater degree.

To evaluate the potential effect time trends in the spawn index may have on estimates of current stock size, we ran a second set of computer runs, for all stock groupings. Observed irregularities in the spawn data determined three blocks of years within which constant spawn measurements were assumed: 1951-68, 1969-75, 1976-82. The true spawn-observed spawn coefficient (CSP) was set at 1 for the first block of years but was allowed to vary for the other two (CSP becomes CSP_k where k is the block of time).

Instantaneous fishing (F_{ij}) and natural (M_{ij}) mortality rates are incorporated in the model through the catch equations :

$$P_{ij}C_i = F_{ij}/(F_{ij} + M_{ij}) \; (\; 1 - \exp(-F_{ij} - M_{ij})) \; N_{ij}$$

The instantaneous fishing mortality rates are defined as described in Fournier and Archibald (1982). Basically, this involves parameters for the average fishing level each year and parameters for age specific selectivity. In this analysis two age specific vulnerability curves are used to account for different selectivities between the reduction and the roe fisheries. The model is set up to allow various forms of instantaneous natural mortality. These include constant natural mortality for all years and ages and density dependent natural mortality (Fournier MS in prep.) where the instantaneous rate is a linear function of the estimated yearly biomass. It turned out that natural mortality rates were not well determined, and in most cases unrealistically high values were estimated. For this reason the rate for the first set of computer runs was set at 0.45, a value similiar to other estimates (e.g. Tester 1955). In the second set of computer runs the natural mortality rate was assumed to be density dependent.

Forecast of spawning stocks for 1983 were calculated by assuming all natural mortality will occur prior to spawning and therefore prior to the roe fishery. The numbers of fish at age prior to the fishery are therefore the numbers estimated at the beginning of the 1982 season minus the number dying through the year. Biomass estimates were calculated by applying average weights at age to the estimated numbers at age.

3.3 Status of Stocks

3.3.1 North

Pertinent parameter estimates and the objective function values for the northern stock groupings are shown in Table 3.1. The results labelled "constant" are those produced from the assumptions of constant natural mortality and spawn index. Those labelled "variable" are the result of the assumptions of density dependent natural mortality and a time dependent spawn index. In all stock groupings density dependent natural mortality followed an inverse relationship. That is, higher natural mortality rates were estimated for lower biomass estimates. This trend was extremely strong in the Queen

Charlotte Islands area where instantaneous natural mortality rates were estimated to vary between 0.22 and 0.86. On the other hand virtually no density dependent natural mortality was indicated for the north coast stock where the mortality rate varied from 0.44 to 0.46. This result is somewhat unbelievable in that biological factors which produce the density dependent effect (eg. predation) would be expected to occur over all the areas. It may however be an artifact of poor stock definition or other model assumptions. The main point to be made here is that there is some indication that the northern herring stocks have density dependent natural mortality and this may become a critical factor when populations are at low levels.

Estimates of the spawn index conversion factors (CSP_k) for the later years, that is for 1969-75 and for 1976-82, are all less than 1. This reinforces our intuitive feeling that the spawn measurements tend to overestimate spawn in recent years relative to the earlier years. As well the relative true spawn-escapement coefficients (QSP) follow trends between areas that would be expected. That is, the estimates for the central coast are 2 to 3 times as high as for the north coast and Queen Charlotte Islands. Spawnings in the central coast tend to be narrower than in the other northern areas and because width measurements are not included in the spawn index these relative coefficients would be expected.

The objective function value is a measure of how well the model assumptions fit the data and as such a heuristic type of assumption validation can be done. The decrease in function value from 580 to 496 for the Queen Charlotte Islands runs, when assumptions of density dependent natural mortality and time dependent spawn trends were included in the model, constitute a reasonable improvement in fit. One may feel justified in believing these assumptions are realistic. In the north coast runs, where the function value decreased from 654 to 648, one is less likely to accept the additional assumptions as valid. Of particular interest is the significantly lower objective function value for the combined northern area over the individual areas (340 vs 580,654,476). This indicates that it is more reasonable to analyze the entire time series of data for the larger geographical area. This may result from significant migration of fish between the smaller areas, or may result from reduction catches on migratory stocks in areas where they do not spawn.

The spawn-recruitment curves and the yearly spawn-recruitment estimates from the age-structured model for the northern area are shown in Fig. 3.1 for the "constant" and "variable" assumptions. High variability around the recruitment curve is shown; this results mostly from the low penalty weight put on the stock-recruitment relationship. Of particular interest are the more recent recruitment predictions. An exceptionally large 1977 year class is evident, followed by very small year classes. The model results indicate that recruitment decreases when the spawning population becomes too large. This may be the current situation.

The estimated numbers of age 3 and older fish for the period 1950-82 for the three northern areas and the combined north under both sets of assumptions are shown in Fig. 3.2. The numbers are estimates for the beginning of the season (July 1) so they will be somewhat higher than pre-fishery stock abundances for the roe fisheries. The number of 3+ fish estimated for the Queen Charlotte Islands in 1982 under the "constant" and

"variable" assumptions are 1,500 million and 1,400 million respectively. This constitutes an average decrease of 28% from the 1981 estimates. The stocks are however still high relative to the historic estimates. The 1982 estimates for the north coast under the two sets of assumptions are 1,800 and 470 million fish. While this is an average increase of 17% over the 1981 estimates, very different stock reconstructions result from the two scenarios. Under the assumption of a constant spawn index, the current abundance of north coast stocks is as high as they have ever been historically. However, the population estimates from the variable spawn index assumption indicate that the stocks did never recover from the reduction crash. This result is more consistent with the current belief of field personnel that the north coast stocks are in poor shape. The estimated numbers of age 3+ fish in 1982 in the central coast are 1,300 and 1,000 million under the "constant" and "variable" assumptions respectively. This is an average 15% decrease from the 1981 estimates. Both scenarios indicate a steady decline in numbers since the relatively high estimates for 1974, however the current state is close to the long term average. The estimated numbers of age 3+ fish in 1982 for the combined northern stocks are 3,100 and 3,300 million for the two sets of assumptions. This is an average decrease of 23% from the 1981 estimates. Current stock estimates are about the same as the historic average.

In general, with the possible exception of the north coast, the northern stocks appear to be in good shape. There has been a decrease in numbers over the last few years; this results primarily from an exceptionally strong 1977 year class followed by relatively small year classes.

3.3.2 South

Model parameter estimates and the objective function values for the southern stock groupings for both sets of runs are shown in Table 3.2. As in the northern areas the "variable" runs assume density dependent natural mortality and time dependent spawn index. The results are fairly consistent between the stock groupings with an average range in the instantaneous natural mortality rate of 0.26 - 0.75. This represents an annual survival rate ranging from 0.47 to 0.77.

The estimates of the spawn index conversion factors for the time periods 1969-75 and 1976-82 are all greater than one with the exception of the first factor for the combined southern area. This is contrary to our belief that more recent spawn measurements overestimate spawn relative to the earlier years. The conversion factors are however close to one (1.1-1.3), which may indicate that the spawn surveys in the southern areas have been more consistent over the time period than in the northern areas. Certainly the spawnings in the south, particularily in the Strait of Georgia, are more accessible and would have had more complete coverage in the early years. The most reasonable assumption for the southern areas would be that the spawn index has been measured consistently through the time period of this analysis.

The estimated stock-recruitment curves and yearly stock-recruitment estimates for the entire southern area are shown in Fig. 3.3. These indicate that recruitment has been relatively low since the 1976 year class. As in the north this may be the result of spawning stocks being too large.

The estimated number of age 3 and older fish for the period 1950-82 for both southern areas and the entire south under both sets of assumptions are shown in Fig. 3.4. The numbers of fish estimated for the Strait of Georgia and Johnstone Strait in 1982 under the "constant" and "variable" assumptions are 1,900 and 1,600 million respectively. These numbers represent an increase of 12% over the 1981 estimates. The 1982 estimates for the west coast of Vancouver Island are 840 and 560 million age 3+ fish under the two scenarios. This represents an increase of 19% from the 1981 estimates for the "constant" assumption and no change for the "variable" assumption. The stock reconstructions indicate a steady decline in numbers since 1974, with current estimates only one third the 1974 levels. The numbers of fish estimated for the entire southern area in 1982 are 2,600 and 1,700 million. These stock levels are the same as the historic average for the assumptions of constant spawn and natural mortality and slightly lower than the historic average for the assumptions of variable spawn and density dependent natural mortality.

3.4 Forecasts

Forecasts of numbers and tons of age 3+ fish prior to the 1983 spawning season and of the potential catch (tons) in 1983 are shown in Table 3.3 for all stock groupings. The potential catch in tons is calculated as 20% of the predicted pre-spawning biomass. The calculation of potential catch contains the implicit assumption that all fish age 3 and older will have recruited to the spawning population. This assumption is not likely true, particularly in the northern areas where a large proportion of fish may not recruit until age 4.

The potential catch predictions for 1983 do not vary greatly between the assumptions of a constant spawn index and natural mortality , and a variable spawn index and density dependent natural mortality for all stock groupings except the north coast. The two potential catch estimates for the north coast are 28,800 t and 7,600 t. The average predictions for the Queen Charlotte Islands and the central coast are 30,000 t and 20,000 t respectively. The average potential catch predicted for the entire northern area is 61,000 t. Potential catch for the west coast of Vancouver Island and for the Strait of Georgia and Johnstone Strait is estimated at 10,700 t and 32,200 t respectively. The prediction for the entire southern area is a potential catch of 33,800 t.

The predicted numbers of fish at age and the predicted age composition of age 3 and older fish in 1983 are shown in Tables 3.4 and 3.5. These indicate relatively poor recruitment of the 1980 year class, that is 3 year olds in 1983, for the northern areas, with the exception of the north coast. The predicted age composition for the southern areas show 3 year olds comprising approximately 50% of the population in 1983. Because there is little information about recruitment prior to age 3 fish spawning, that is relatively few age 2 fish are caught in the fisheries, the model's prediction for recruitment of the 1980 year class is primarily based on estimated spawn in that year and the stock- recruitment parameters. The pre-fishery biomass estimates and therefore potential catch estimates would be greatly enhanced with prior knowledge of recruitment and age-specific maturation rates.

Table 3.1 Model parameter estimates and objective function values for the northern stock groupings.

	Objective Function Value	Instantaneous Natural Mortality rate	True Spawn-Escapement Coefficient (QSP)	Spawn Index conversion factor (CSP_k) 1965-75	1976-82
Queen Charlotte Islands-constant[a]	580.	0.45	0.087	0.56	0.37
-variable[b]	496.	0.22-0.86	0.062		
North Coast-constant	654.	0.45	0.093	0.71	0.29
-variable	648.	0.44-0.46	0.085		
Central Coast-constant	476.	0.45	0.23	0.59	0.80
-variable	459.	0.31-0.67	0.21		
Combined North-constant	340.	0.45	0.17	0.65	0.57
-variable	320.	0.30-0.69	0.14		

[a]"constant" assumes constant natural mortality and spawn index.

[b]"variable" assumes density dependent natural mortality and time dependent spawn index.

Table 3.2. Model parameter estimates and objective function values for the southern stock groupings.

		Objective Function Value	Instantaneous Natural Mortality Rate	True Spawn-Escapement Coefficient (QSP)	Spawn Index conversion factor (CSP_k) 1969-75	1976-82
Strait of Georgia and Johnstone Strait	-constant[a]	379	0.45	0.36		
	-variable[b]	365	0.31-0.71	0.44	1.17	1.32
West Coast of Vancouver Island	-constant	360	0.45	0.25		
	-variable	335	0.20-0.67	0.32	1.15	1.17
Combined Southern Area	-constant	305	0.45	0.32		
	-variable	273	0.28-0.87	0.39	0.75	1.15

[a]"constant" assumes constant natural mortality and spawn index.

[b]"variable" assumes density dependent natural mortality and time dependent spawn index.

Table 3.3. Forecast of the 1983 runs and potential catch.

Area	Millions of Age 3+ fish in 1982	Millions of Age 3+ fish prior to 1983 spawning	Tons of Age 3+ fish prior to 1983 spawning	Potential catch in tons
Queen Charlotte Islands				
-constant[a]	1,550	990	149,000	29,800
-variable[b]	1,400	1,010	153,000	30,600
North Coast				
-constant	1,770	1,130	144,000	28,800
-variable	470	300	38,000	7,600
Central Coast				
-constant	1,340	850	116,000	23,200
-variable	1,000	620	87,000	17,400
Total North				
-constant	3,090	1,970	286,000	57,200
-variable	3,300	2,230	324,000	64,800
West Coast of Vancouver Island				
-constant	840	540	66,000	13,200
-variable	560	330	41,000	8,200
Strait of Georgia/Johnstone Strait				
-constant	1,910	1,220	178,000	35,600
-variable	1,620	1,030	150,000	30,000
Total South				
-constant	2,590	1,650	209,000	41,800
-variable	1,700	1,010	129,000	25,800

a"constant" assumes constant natural mortality and spawn index.

b"variable" assumes density dependent natural mortality and time dependent spawn index.

Table 3.4. Predicted millions of age 3 and older fish in 1983.

	Age								
	3	4	5	6	7	8	9	10	Total
Queen Charlotte Islands									
-constant[a]	97.8	282.8	41.7	487.2	18.3	37.6	20.9	5.0	991.4
-variable[b]	107.1	239.3	38.4	517.8	20.9	47.8	29.2	7.9	1008.4
North Coast									
-constant	533.6	217.9	112.2	229.6	15.3	6.9	10.7	1.6	1127.8
-variable	138.7	56.9	30.5	62.8	4.2	1.9	2.6	0.3	297.9
Central Coast									
-constant	298.0	207.9	68.6	167.1	12.9	64.9	19.9	14.9	854.1
-variable	172.3	153.5	53.7	141.2	8.8	59.0	19.7	15.2	623.4
Total North									
-constant	354.9	479.0	147.3	834.2	48.7	54.1	35.9	13.0	1967.1
-variable	393.4	561.8	178.4	929.9	54.7	61.4	41.1	15.1	2235.7
West Coast of Vancouver Island									
-constant	286.6	111.5	62.0	34.2	9.7	23.2	3.8	5.9	536.9
-variable	165.5	66.5	39.6	22.5	6.9	18.6	3.5	5.8	328.8
Strait of Georgia/Johnstone Str.									
-constant	581.5	331.6	121.1	79.7	31.4	39.3	25.5	6.8	1216.8
-variable	499.0	277.5	99.8	65.4	25.5	32.8	21.5	5.8	1027.4
Total South									
-constant	784.2	395.8	192.4	125.5	42.8	66.9	29.2	14.9	1651.7
-variable	449.6	256.6	125.0	78.2	26.0	44.8	19.9	10.4	1010.5

[a]"constant" assumes constant natural mortality and spawn index.

[b]"variable" assumes density dependent natural mortality and time dependent spawn index.

Table 3.5. Predicted proportion (%) of fish at age 3 and older in 1983.

	Age							
	3	4	5	6	7	8	9	10
Queen Charlotte Is.								
-constant[a]	9.86	28.53	4.21	49.14	1.85	3.79	2.11	0.50
-variable[b]	10.62	23.73	3.81	51.35	2.07	4.74	2.90	0.78
North Coast								
-constant	47.31	19.32	9.95	20.36	1.36	0.61	0.95	0.14
-variable	46.56	19.10	10.24	21.08	1.41	0.64	0.87	0.10
Central Coast								
-constant	34.89	24.34	8.03	19.56	1.51	7.60	2.33	1.74
-variable	27.64	24.62	8.61	22.65	1.41	9.46	3.16	2.44
Total North								
-constant	18.04	24.35	7.49	42.41	2.48	2.75	1.83	0.66
-variable	17.60	25.13	7.98	41.59	2.45	2.75	1.84	0.67
West Coast Vancouver Island								
-constant	53.38	20.77	11.55	6.37	1.81	4.32	0.71	1.10
-variable	50.33	20.23	12.04	6.84	2.10	5.66	1.06	1.76
Strait of Georgia/Johnstone Str.								
-constant	47.79	27.25	9.95	6.55	2.58	3.23	2.09	0.56
-variable	48.57	27.00	9.71	6.37	2.48	3.19	2.09	0.56
Total South								
-constant	47.48	23.96	11.65	7.60	2.59	4.05	1.77	.90
-variable	44.49	25.39	12.37	7.74	2.57	4.43	1.97	1.03

[a]"constant" assumes constant natural mortality and spawn index.

[b]"variable" assumes density dependent natural mortality and time dependent spawn index.

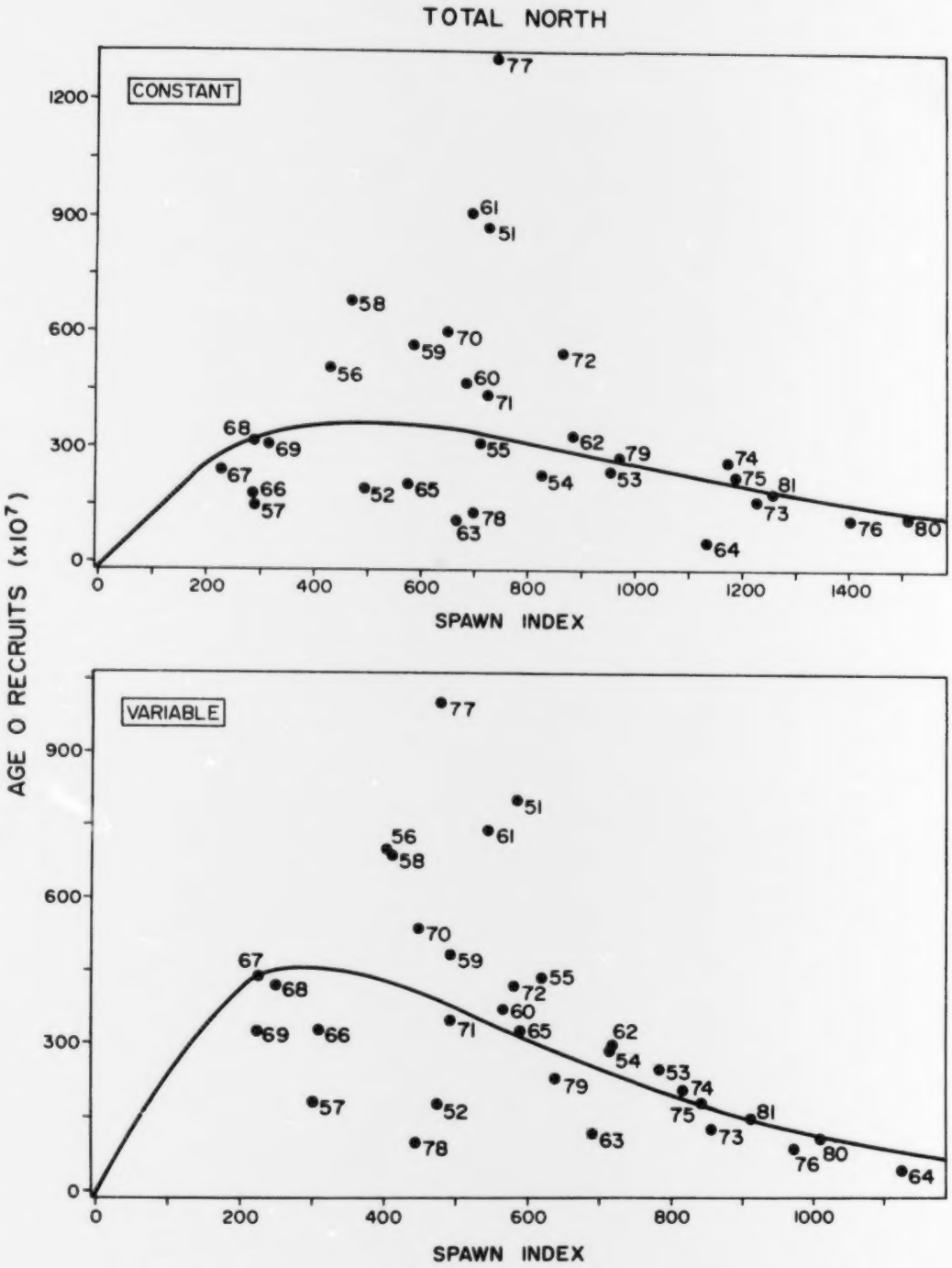

Fig. 3.1. Spawn-recruitment relationships for northern herring for the "constant" and "variable" assumptions.

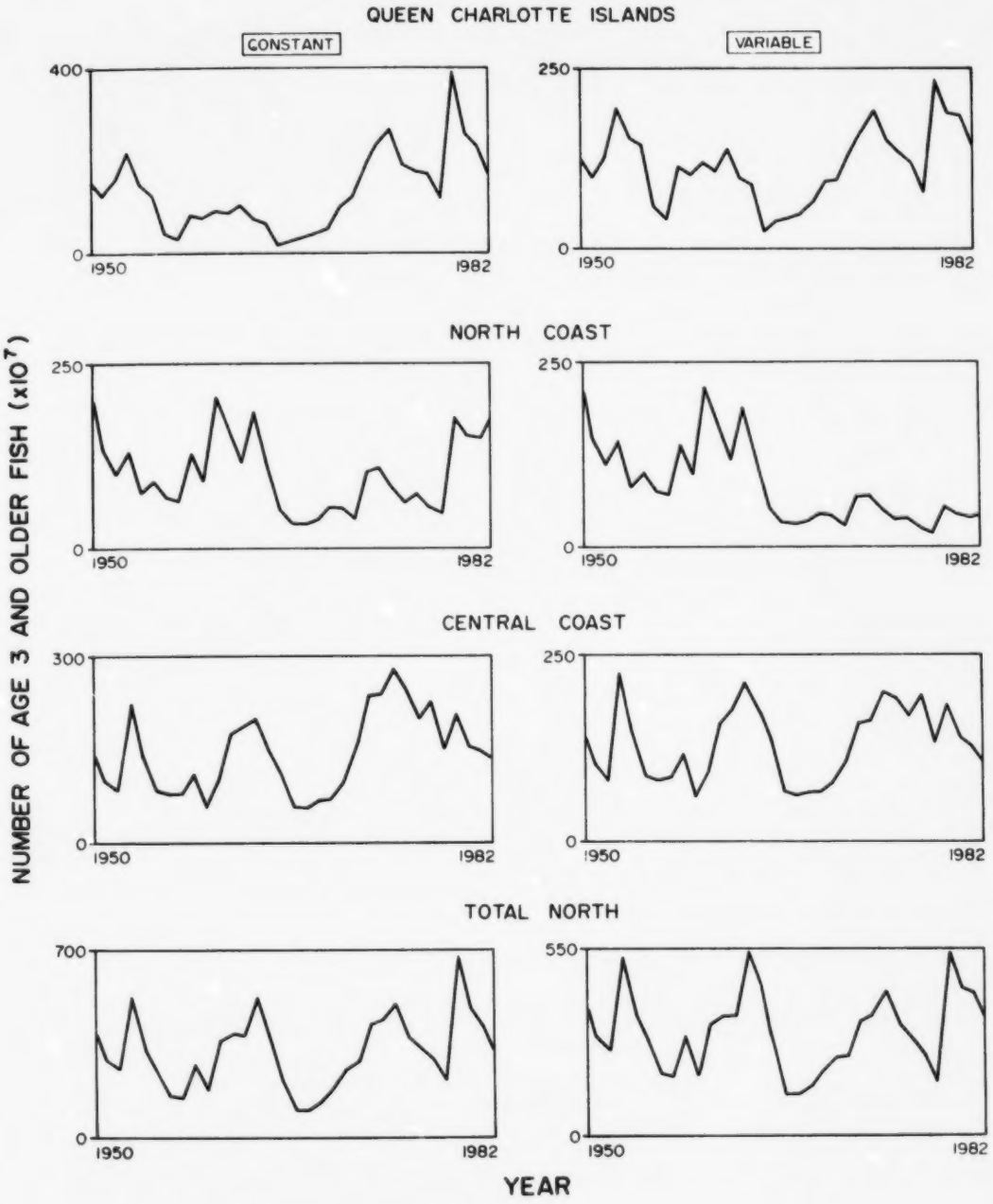

Fig. 3.2. Estimated numbers of age 3 and older northern herring, 1951-82.

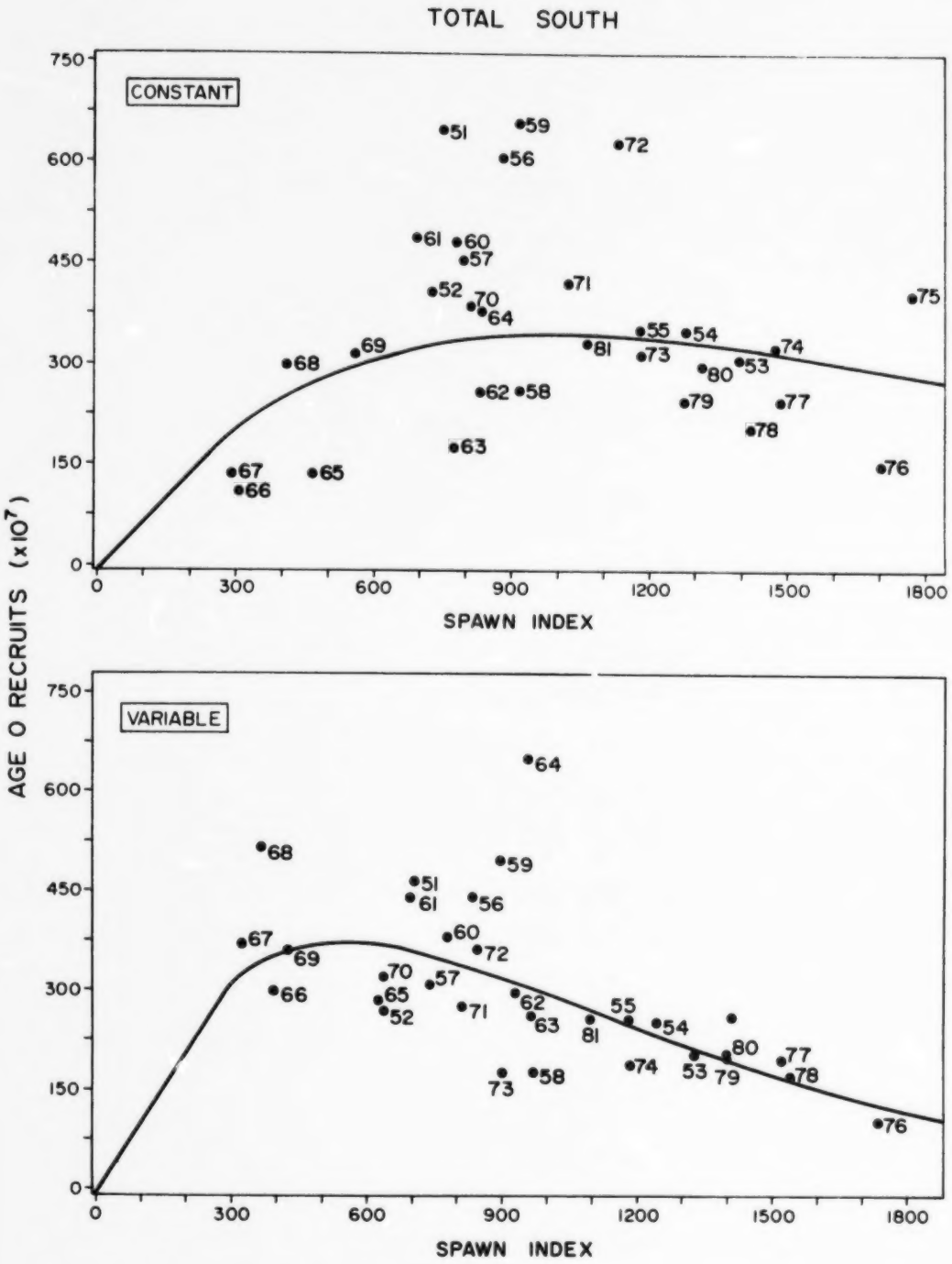

Fig. 3.3. Spawn-recruitment relationships for southern herring for the "constant" and "variable" assumptions.

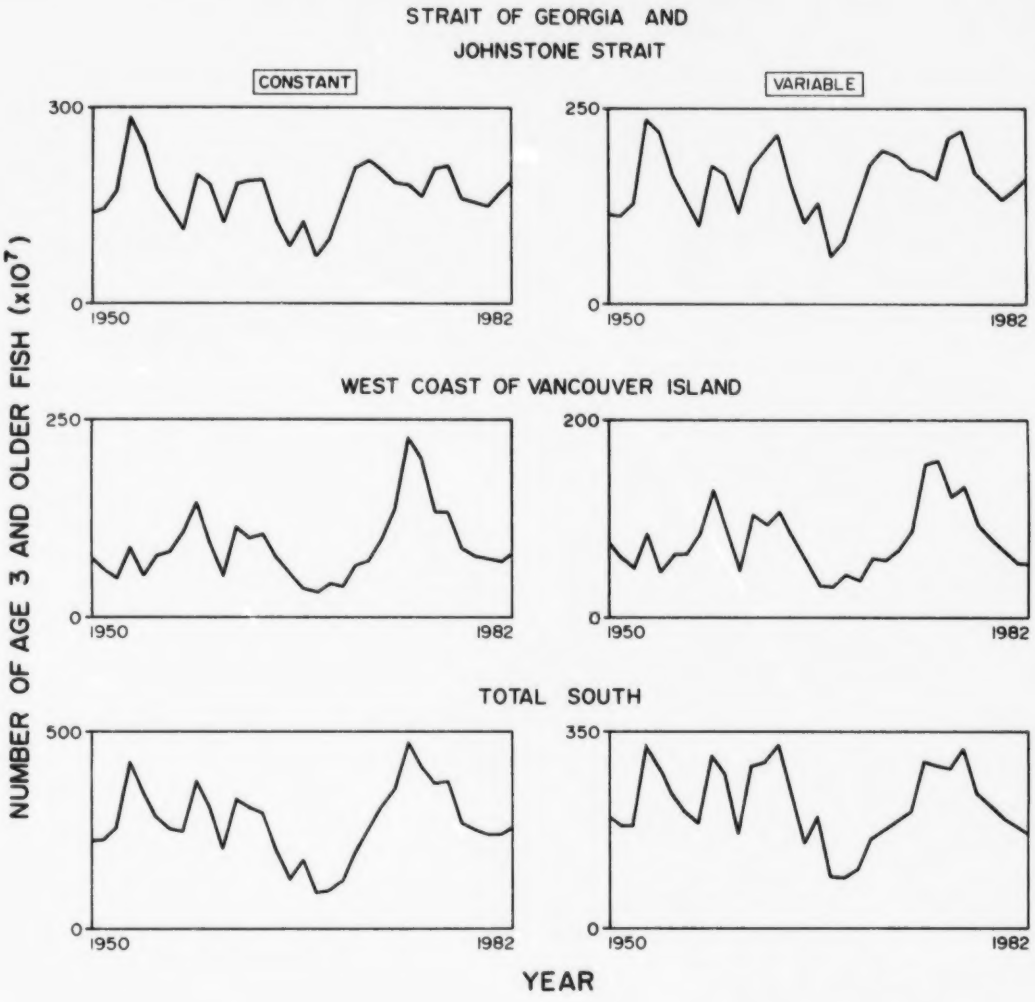

Fig. 3.4. Estimated numbers of age 3 and older southern herring, 1951-82.

4. SURPLUS PRODUCTION MODEL ANALYSIS

4.1 Introduction

In surplus production models changes in productivity are expressed in quantitative relationships. Based on productivity estimates, catch estimates are predicted for stocks. We assume that the proportion of the stock dying each year increases with stock size and also that the number of births increase as stock size increases. The difference between births and deaths at any stock size is the source of surplus production to be harvested.

4.2 Methods

A measure of herring abundance of the different stocks based on a Spawn Index (S) was used for these analyses. The following relationship between catch and Spawn Index for the years 1951-82 was examined to assess stock sizes and productivity:

$$B_{t+1} = B_{t.s} + \frac{\alpha B_{t-n}}{\beta + B_{t-n}} - C_{t+1}$$

where B_t = spawning biomass in year t
C_t = catch in year t
s_t = annual natural survival fraction
n = lag period in years
α, β = production parameters.

The relationship between Spawn Index (S) and biomass (B) was modelled as:

$$B = S/q$$

where q = proportionality constant.

Estimates of the Spawn Index were obtained from historical spawn data by summing the length of spawn multiplied by the observed intensities. The critical parameter in this analysis is the proportionality constant q. To estimate biomass for this analysis four alternative values were used: $q = 0.003$, $q = 0.006$, $q = 0.009$, and q = variable. Variable q implies that over time spawn indices have been collected in different ways and/or ability in detecting spawn may have changed over time. There seems a fair amount of evidence for this assumption to hold.

The production of the population, which is the second term on the right-hand side of the model, is the difference between pre-fishery biomass in a given year ($B_{t+1} + C_{t+1}$) and the surviving spawning biomass the previous

year (B_t's). It turned out that production parameter estimates of α and β used in predicting production did not perform better than using average production from 1954-81. Thus, for forecasting 1983 stock sizes ($B_{83} + C_{83}$) we used the simple relationship:

$$B_{83} + C_{83} = B_{82} .s + \text{average production} \pm 1SD.$$

A simple procedure was used to calculate recommended catch quotas. The catch quotas are established at 20% of the forecast 1983 stock sizes.

4.3 Status of stocks

4.3.1 North

Spawn indices (S) and catch (tons) for the years 1951-82 are summarized in Table 4.1 for the three northern Divisions as well as the entire North. Pre-fishery abundance for the years 1951-82 in relation to proportionality constant q are shown in Fig. 4.1 for the northern stock groupings. The 1982 pre-fishery biomass for the Queen Charlotte Islands was estimated at 105,000 t and 80,000 t for q = 0.006 and q = variable, respectively. This represents an 11% increase over the 1981 pre-fishery biomass. For the north coast the estimates are 32,000 t and 24,000 t for the two q assumptions, which is down by 18% from 1981. The central coast pre-fishery biomass for 1982 was estimated as 112,000 t and 86,000 t for the two cases indicating a decline of 4% from the previous year. For the entire north the abundance of the 1982 pre-fishery biomass was estimated as 249,000 t and 191,000 t for the two proportionality constant assumptions, respectively. This presents a slight decrease from the previous year of 1%. Generally, in the north there has been an increase in pre-fishery biomass since 1978 which is probably mainly attributable to the strong 1977 year-class.

Production for the entire north resulting from spawning stocks for the period 1954-81 is shown in Fig. 4.2b. This production is for the case where q is assumed to be variable over time (Fig. 4.2a). Great variability in production has occurred over the time period considered, with an average production of 115,000 t with a standard deviation of 64,000 t. Similar variability in production is observed from the separate stock groupings for Queen Charlottes, north coast, and central coast. As pointed out, for forecasting 1983 pre-fishery biomass the average production with the appropriate standard deviations were used. This is disappointing but it can hardly be justified to fit a dome-shaped production relationship to this data.

4.3.2 South

Spawn indices (S) and catch (tons) for the period 1951-82 are summarized in Table 4.2 for the two southern groups as well as the entire south. Pre-fishery abundances for the period 1951-82 in relation to proportionality constant q are shown in Fig. 4.3 for the southern stock groupings. The 1982 pre-fishery biomass for the west coast of Vancouver Island was estimated as 49,000 t and 39,000 t for q = 0.006 and q = variable, respectively. This represents a substantial decline of 31% since 1981. For

the Gulf of Georgia and Johnstone Strait the estimates are 150,000 t and 116,000 t for the two q assumptions, which is up by 26% from the 1981 pre-fishery biomass. For the entire South the abundance of the 1982 pre-fishery biomass was estimated as 198,000 t and 155,000 t for the two proportionality constant assumptions, respectively. This presents an increase of 4% over the previous year. Generally, in the South there has been a decline since 1980 indicating a lack of strong production of recruits in recent years.

4.4 Forecast

Forecasts of the 1983 runs and potential catch of herring for low, average, and high production are summarized in Tables 4.3 and 4.4 for the north and south respectively.

Assuming average production and a variable proportionality constant q, a run of 220,000 t is forecast for the northern district (Table 4.3). Based on a 20% exploitation rate, the average potential catch would be 44,000 t, with a range of 31,000 t to 57,000 t depending on the production assumption of low and high respectively.

A run of 74,000 t is forecast for the Queen Charlotte Islands, assuming average production and variable q. This would provide a quota of 15,000 t for that district. Abundance is forecast to remain relatively low in 1983 for the north coast district. A run of 36,000 t with a potential quota of 7,000 t is predicted for an average production year. The 110,000 t run forecast for the central coast district, assuming variable q and average production, would leave a potential quota of 22,000 t.

Assuming average production and q=0.009, a run of 165,000 t is forecast for the southern district. The latter assumption is based on more consistent spawn observations over time in the southern district. Based on the 20% recommended exploitation rate the average potential catch would amount to 33,000 t, ranging from 23,000 t to 43,000 t depending on the production being low or high respectively.

Abundance is forecast to remain relatively low in the west coast of Vancouver Island district in 1983. A run of 45,000 t with a potential quota of 9,000 t is predicted for an average production year and q=0.009. The surplus production analysis predicts a run of 117,000 t for the Strait of Georgia and Johnstone Strait district in 1983. This would provide a quota of 23,000 t for an average production year.

Table 4.1. Spawn index (S) and catch (tons) by Division for the North, 1951-82.

	Division							
	Queen Charlotte Islands		North Coast		Central		Total North	
Year	S	Catch (tons)	S	Catch (tons)	S	Catch (tons)	S	Catch (tons)
1951	70	3,138	226	50,557	402	49,830	698	103,525
1952	49	11,370	127	57,737	212	40,154	388	109,260
1953	121	0	186	2,056	454	854	760	2,902
1954	192	28,680	145	30,067	379	32,478	716	91,224
1955	99	22,323	198	19,627	386	34,842	683	76,792
1956	86	92,218	165	11,223	273	49,602	524	153,042
1957	25	27,768	287	30,902	144	43,500	456	102,170
1958	18	12,562	109	4,985	232	14,094	359	31,641
1959	223	19,368	193	11,270	254	39,441	670	70,079
1960	141	3,420	171	20,366	461	11,928	774	35,714
1961	201	2,877	148	47,119	256	42,496	605	92,491
1962	142	16,209	263	30,489	486	40,387	890	87,085
1963	114	19,422	106	44,343	222	65,064	442	128,829
1964	122	35,347	184	33,443	316	55,510	622	124,300
1965	40	46,700	59	48,733	233	28,750	332	124,183
1966	49	7,162	37	19,064	121	62,050	207	88,278
1967	24	839	26	8,816	328	36,886	378	46,541
1968	24	173	57	2,363	238	3,971	318	6,507
1969	61	187	11	603	124	110	195	899
1970	105	0	149	1,652	672	260	926	1,912
1971	212	443	124	3,858	722	4,472	1,058	8,771
1972	243	4,600	132	4,954	664	12,323	1,038	21,877
1973	235	9,453	118	1,771	992	11,240	1,344	22,464
1974	316	7,904	96	4,210	774	11,130	1,186	23,244

Table 4.1 (cont'd)

Year	Division							
	Queen Charlotte Islands		North Coast		Central		Total North	
	S	Catch (tons)	S	Catch (tons)	S	Catch (tons)	S	Catch (tons)
1975	263	9,009	105	1,876	766	10,885	1,134	21,770
1976	403	15,852	171	4,747	1,054	14,410	1,628	35,010
1977	396	14,179	129	8,974	864	12,287	1,389	35,440
1978	351	13,758	77	9,466	393	15,546	821	38,770
1979	319	9,994	153	4,758	571	5	1,042	14,758
1980	566	3,790	218	3,775	645	594	1,429	8,159
1981	523	7,623	211	3,406	684	3,306	1,418	14,335
1982	593	6,364	176	2,190	628	7,449	1,397	16,003

Table 4.2. Spawn index (S) and catch (tons) by Division for the South, 1951-82.

Year	Division				Total South	
	West Coast Vancouver Island[oo]		Gulf of Georgia & Johnstone Strait			
	S	Catch (tons)	S	Catch (tons)	S	Catch (tons)
1951	226	24,284	554	52,261	780	76,545
1952	128	29,812	676	58,926	804	88,738
1953	373	22	1,474	9,286	1,847	9,308
1954	231	41,417	946	78,832	1,177	122,367
1955	248	13,850	889	77,725	1,137	91,835
1956	309	19,406	491	81,164	800	100,618
1957	376	3,407	352	79,930	727	86,357
1958	242	612	486	25,868	727	38,062
1959	152	76,891	596	61,330	748	138,748
1960	132	61,505	684	84,402	815	145,907
1961	202	34,000	558	57,118	760	91,170
1962	351	31,277	423	83,333	774	132,118
1963	162	23,423	603	87,289	764	135,178
1964	534	24,409	588	98,832	1,121	137,437
1965	236	20,727	372	71,818	609	114,114
1966	84	13,642	296	59,087	380	92,062
1967	87	17,010	253	50,543	340	83,387
1968	97	0	341	5,815	439	7,700
1969	145	0	603	914	748	914
1970	345	0	1,041	1,010	1,386	1,010
1971	311	0	882	1,971	1,193	1,971
1972	329	0	797	14,423	1,126	22,022
1973	224	20,175	662	18,700	886	38,875
1974	181	18,585	1,017	6,956	1,198	25,544

Table 4.2 (cont'd)

Year	Division				Total South	
	West Coast Vancouver Island[a]		Gulf of Georgia & Johnstone Strait			
	S	Catch (tons)	S	Catch (tons)	S	Catch (tons)
1975	354	28,779	1,189	8,367	1,544	37,146
1976	364	42,946	841	15,267	1,205	58,216
1977	341	33,224	820	20,197	1,161	53,421
1978	327	25,237	767	27,324	1,094	52,622
1979	493	21,369	865	22,577	1,358	43,946
1980	574	4,962	994	6,490	1,569	11,452
1981	371	9,643	635	13,469	1,006	23,112
1982	244	8,591	799	16,650	1,043	24,241

[a]Does not include offshore catch Areas 20-21.

Table 4.3 Forecast of the 1983 runs and potential catch in tons of fish for the North for low, average, and high production in relation to proportionality constant q.

Division	Spawners 1982	Survivors	Average Production	S.D.	Forecast Run Low	Forecast Run Average	Forecast Run High	Potential Catch Low	Potential Catch Average	Potential Catch High
Queen Charlottes										
q = 0.003	197,666	118,600	42,993	32,570	129,023	161,593	194,163	26,000	32,000	39,000
q = 0.006	98,833	59,300	27,528	19,887	66,939	86,826	106,713	13,000	17,000	21,000
q = 0.009	65,889	39,533	22,372	17,266	44,639	61,905	79,171	9,000	12,000	16,000
q = variable	74,125	44,475	29,348	20,793	53,030	73,023	94,616	10,000	15,000	19,000
North Coast										
q = 0.003	58,667	35,200	30,660	26,214	39,646	65,860	92,074	8,000	13,000	18,000
q = 0.006	29,333	17,600	21,334	18,224	20,710	38,934	57,158	4,000	8,000	11,000
q = 0.009	19,556	11,734	18,223	16,356	13,601	29,957	46,313	3,000	6,000	9,000
q = variable	22,000	13,200	22,534	18,336	17,399	35,734	54,070	3,000	7,000	11,000
Central										
q = 0.003	209,333	125,600	87,071	58,340	154,331	212,671	271,011	31,000	42,000	54,000
q = 0.006	104,667	62,800	54,032	29,798	87,034	116,872	146,630	17,000	23,000	29,000
q = 0.009	69,778	41,867	43,019	22,756	62,130	84,886	107,642	12,000	17,000	21,000
q = variable	78,500	47,100	63,089	45,902	64,287	110,189	156,091	13,000	22,000	31,000
Total North										
q = 0.003	465,667	279,400	160,724	83,483	356,641	440,124	523,607	71,000	88,000	105,000
q = 0.006	232,833	139,700	102,894	48,409	194,185	242,594	291,003	39,000	48,000	58,000
q = 0.009	155,222	93,133	83,614	42,228	134,519	176,747	218,975	27,000	35,000	44,000
q = variable	174,625	104,775	114,971	64,540	155,206	219,746	284,286	31,000	44,000	57,000

Table 4.4 Forecast of the 1983 runs and potential catch in tons of fish for the South for low, average, and high production in relation to proportionality constant q.

Division	Spawners 1982	Survivors	Average Production	S.D.	Forecast Run Low	Forecast Run Average	Forecast Run High	Potential Catch Low	Potential Catch Average	Potential Catch High
West Coast of Vancouver Island										
q = 0.003	81,333	48,800	53,468	42,660	59,608	102,268	144,928	12,000	20,000	29,000
q = 0.006	40,667	24,400	34,815	25,805	33,410	59,215	85,020	7,000	12,000	17,000
q = 0.009	27,111	16,267	28,597	21,417	23,447	44,864	66,281	5,000	9,000	13,000
q = variable	30,500	18,300	37,344	27,793	27,851	55,644	83,437	6,000	11,000	17,000
Gulf of Georgia & Johnstone Strait										
q = 0.003	266,333	159,800	123,070	57,681	225,189	282,870	340,551	45,000	57,000	68,000
q = 0.006	133,167	79,900	78,728	35,927	122,701	158,628	194,555	25,000	32,000	39,000
q = 0.009	88,778	53,267	63,948	32,128	85,087	117,215	149,343	17,000	23,000	30,000
q = variable	99,875	59,925	86,460	45,725	100,660	146,385	192,110	20,000	29,000	38,000
Total South										
q = 0.003	347,667	208,600	180,219	83,286	305,533	388,819	472,105	61,000	78,000	94,000
q = 0.006	173,833	104,300	117,227	55,021	166,506	221,527	276,548	33,000	44,000	55,000
q = 0.009	114,889	68,933	96,229	49,643	115,519	165,162	214,805	23,000	33,000	43,000
q = variable	130,375	78,225	127,489	65,339	140,375	205,714	271,053	28,000	41,000	54,000

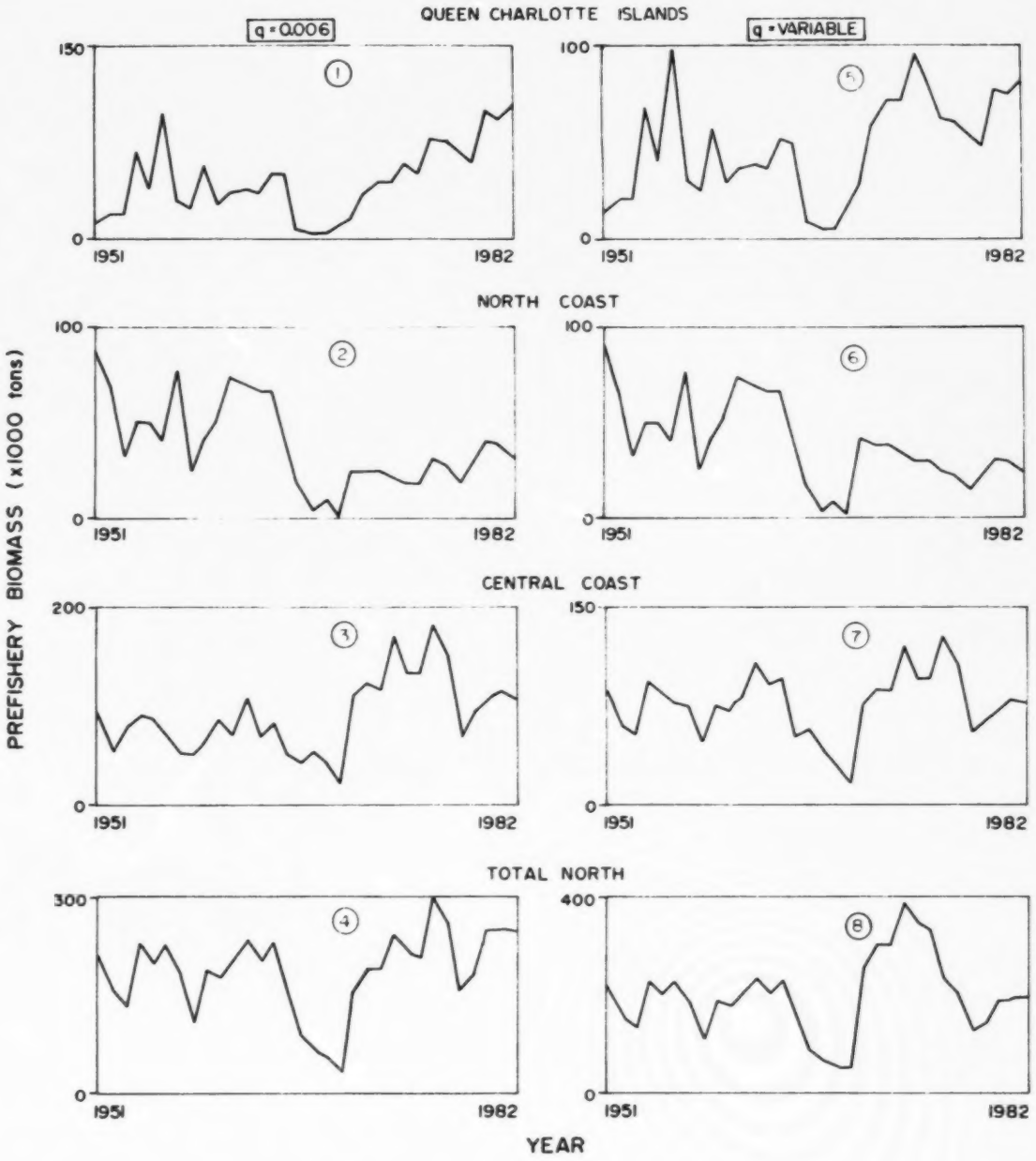

Fig. 4.1. Pre-fishery biomass estimates for northern herring, 1951-82.

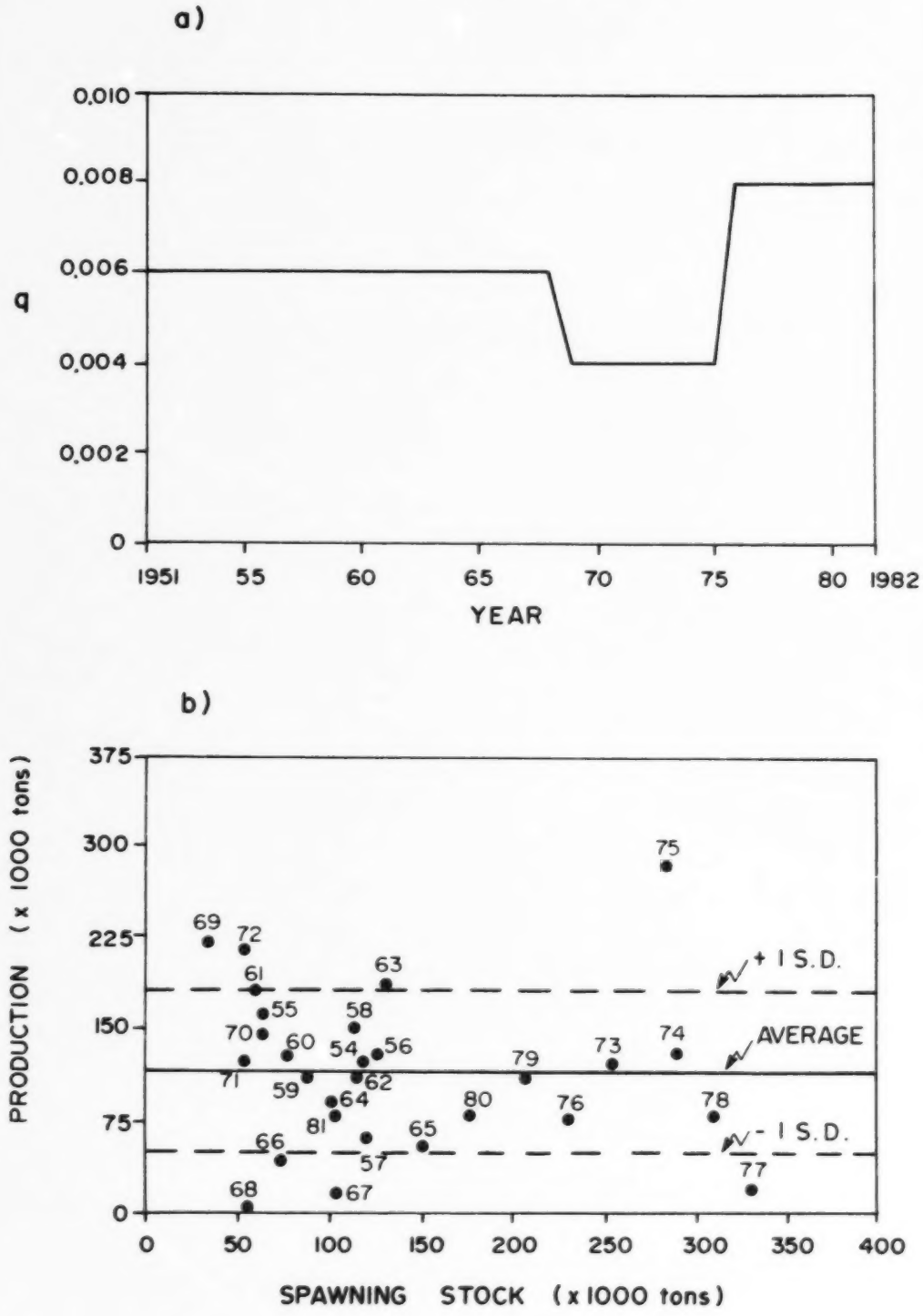

Fig. 4.2. (a) Time variable proportionality constant, and (b) northern herring production, 1951-82.

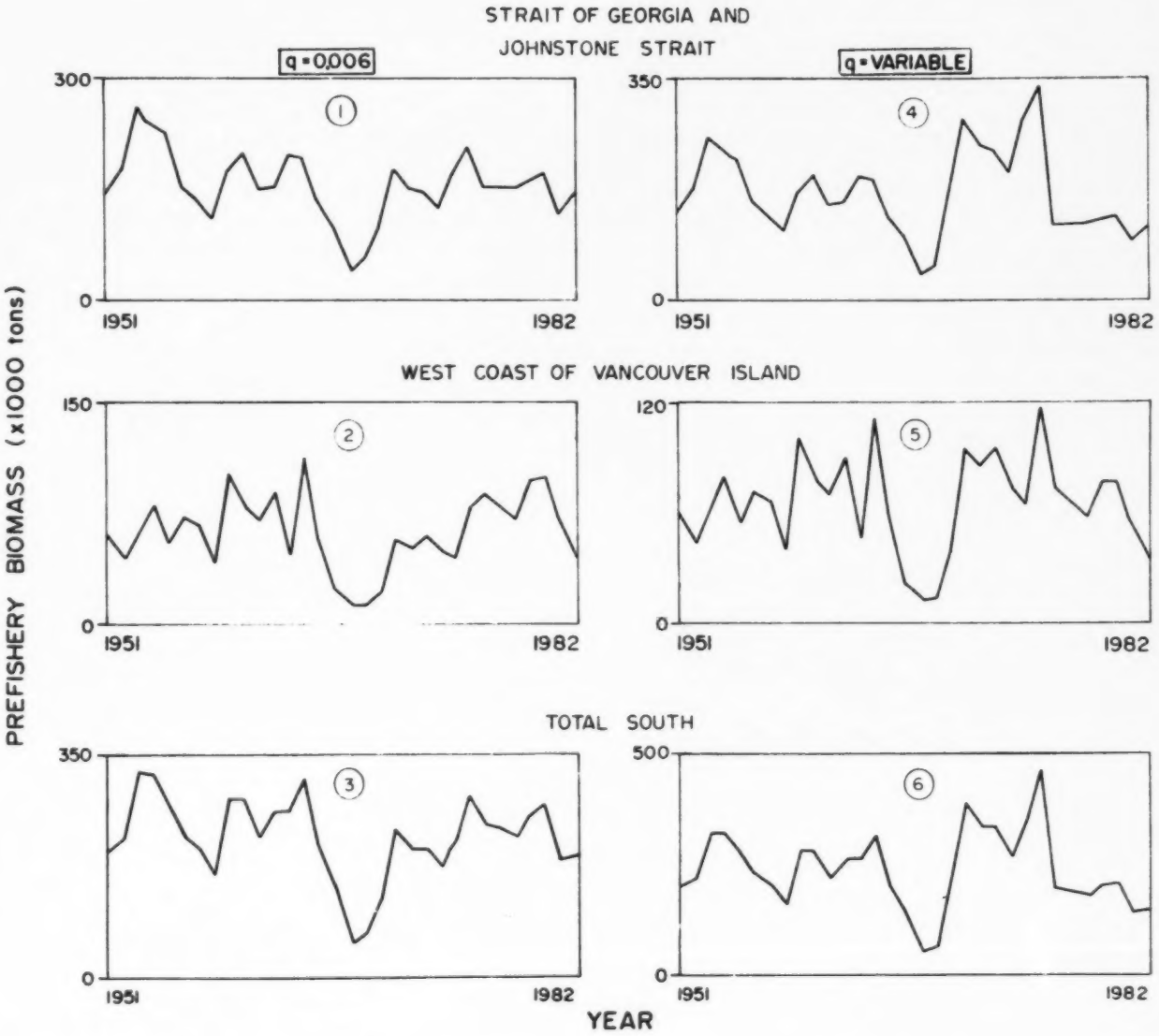

Fig. 4.3. Pre-fishery biomass estimates for southern herring, 1951-82.

5. DISCUSSION

The forecasts of runs for 1983 are based on three different methods. Although all methods produce similar long-term trends in biomass for the various British Columbia herring stocks, age-structured analysis and surplus production analysis produce more concordant and reasonable estimates for 1983. Each method has a different set of assumptions and limitations. These methods will continue to be refined as we learn more about the dynamics of herring populations. The age-structured method is preferred for biomass estimation and forecasting. This model combines available biological information in a systematic way with catch at age data to produce a comprehensive analysis of past behavior of exploited British Columbia herring populations. The model has the correct stochastic orientation, meaning that both the information submitted to the model and the underlying processes are subject to error, and that these errors are allocated in a reasonable fashion. The model is also very flexible. This allowed us to examine various assumptions regarding natural mortality, and time trends in the spawn index. In future we will also be able to examine effects of environmental factors on recruitment. Another advantage of this model is the objective way in which assumptions are evaluated. The goodness of fit for the various runs is measured by the objective function value. The lower the value, the better the data fit model assumptions. This procedure is commonly referred to as a heuristic assumption validation.

Many methods can be used to regulate fisheries. Setting catch quotas, or setting rigid spawning stock goals are two possibilities. Hourston's method follows the latter policy. However, we feel considering the uncertainties about what constitutes optimum spawning stock sizes, and the difficulty in assessing prefishery stock sizes that this management option is currently impractical. For these reasons, we recommend conservative exploitation rates of 20% of forecast runs. These low exploitation rates will produce less variable catches, and perhaps dampen any fluctuations due to dome shaped recruitment relationships. The latter point follows from the notion that natural fluctuations may be greatly exaggerated if we fish harder following the appearance of strong year classes.

The forecasts presented herein are based on average productivity of stocks for 1983. For the entire north the forecast is 102,000 t from Hourston's method, 324,000 t from the age-structured method, or 220,000 t from surplus production analysis. With the exception of the north coast (Areas 3-5) the northern stocks are in good condition, and catch levels have been recommended accordingly. For the south the forecast is 265,000 t from Hourston's method, 129,000 t from the age-structured method, or 165,000 t for surplus production analysis. The current population off the west coast of Vancouver Island is below historical levels and current management recommendations are such that a rebuilding of the population should occur. The Strait of Georgia population appears healthy and major fisheries are recommended for this population.

The catches recommended herein include all fisheries. Thus catches from food, bait, and special fisheries should be subtracted from recommended catches when roe herring quotas are established.

We should point out that management of the various fisheries has practical constraints other than the biological considerations discussed in this report. Thus catches recommended herein may not be adopted in the final management plan announced by the Department.

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